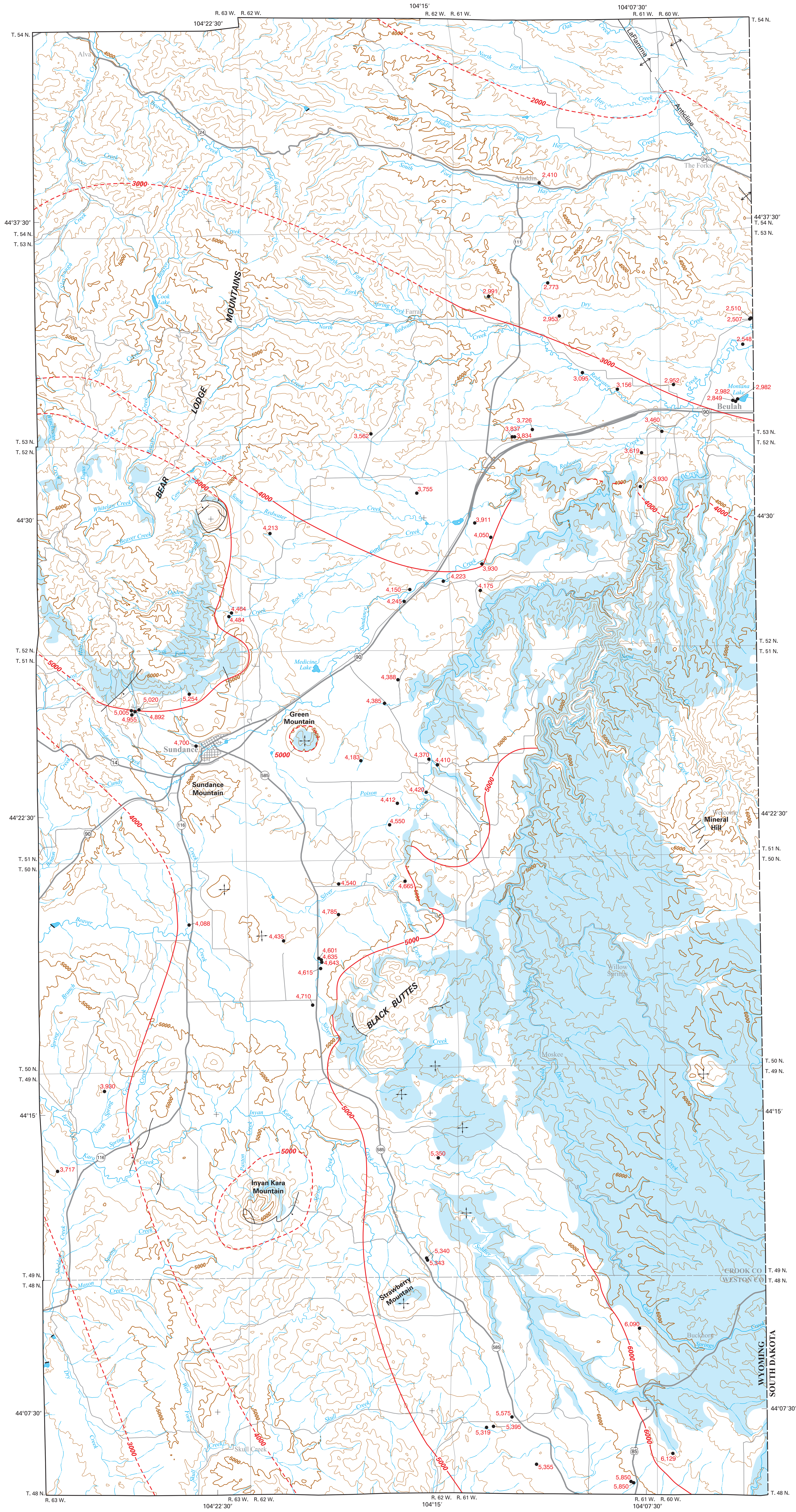


Planimetric base modified from U.S. Geological Survey digital data, 1:100,000: Devil's Tower, 1979; Lance Creek, 1981; Newcastle, 1979; and Sundance, 1979
Universal Transverse Mercator projection, Zone 13
North American Horizontal Datum 1927
Surface elevation contours derived from U.S. National Elevation Database (NED), 1999

Geology modified from Lisenbee (1985) and DeWitt and others (1989)

Altitude of the Top of the Minnelusa Aquifer (northern part of the study area)

SCALE 1:100,000

LAND SURFACE CONTOUR INTERVAL 200 FEET
NORTH AMERICAN VERTICAL DATUM OF 1988

EXPLANATION

- Outcrop of Minnelusa Formation (Lower Permian and Pennsylvanian)
- Outcrop of Madison (Pahasapa) Limestone (Lower Mississippian) and Englewood Formation (Lower Mississippian and Upper Devonian)
- 2000 **Structure contour**—Shows approximate altitude of the top of the Minnelusa or Madison aquifers, in feet. Contour interval 1,000 feet. Dashed where inferred or approximated. Datum is sea level[1]
- **Fault**—Dashed where concealed. Bar and ball on downthrown side
- **Anticline**—Showing trace of axial plane and direction of plunge. Dashed where concealed
- **Dome**—Symbol size approximately proportional to size of dome. Dome asymmetry indicated by arrow length
- 2,410 **Well**—Number is altitude of the top of the aquifer in feet above sea level[1]

[1]Sea level: In this report, the term "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)

MADISON AQUIFER

In this report, the Madison aquifer is defined as equivalent to the Madison Limestone. The reader should note that the Madison Limestone is considered equivalent to the Pahasapa Limestone by most investigators and for purposes of this study. In many areas in Wyoming, large quantities of high-quality water, sometimes under artesian pressure, can be obtained from the Madison aquifer. In the Black Hills of Wyoming and South Dakota, high yields are reported for wells completed in the Madison aquifer, so the aquifer is used when high yields are needed, primarily by municipalities, subdivisions, rural water systems, irrigators and petroleum companies (for secondary oil recovery). Most of the outcrop of the Madison aquifer in the Black Hills is located in South Dakota, so most of the recharge to the aquifer is likely to occur in South Dakota. For mapping purposes, the Madison Limestone was combined with the underlying Englewood Formation by DeWitt and others (1989). The mapped outcrop areas for the Madison aquifer presented in this report are from DeWitt and others (1989), so the reader should note that the outcrop areas probably indicate more of the Madison aquifer at the land surface than is actually present. Most of the available data characterizes the upper part of the Madison aquifer.

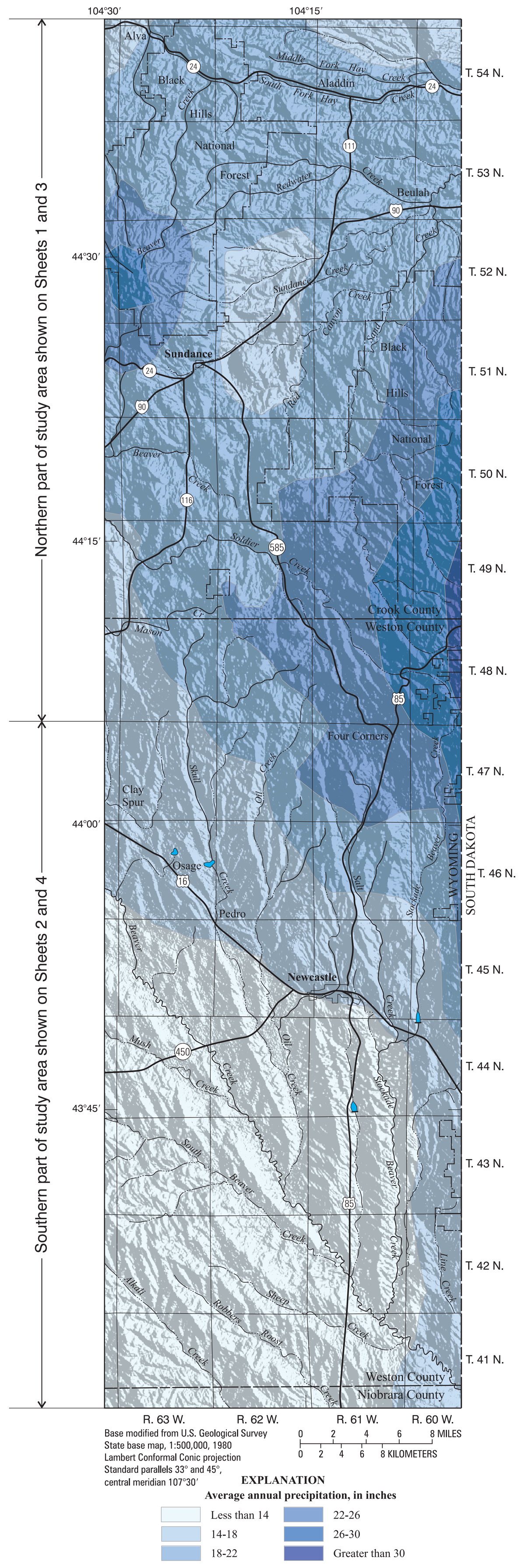


Figure 4. Average annual precipitation (1961-1990) for the study area (modifed from Oregon Climate Service, 1995).

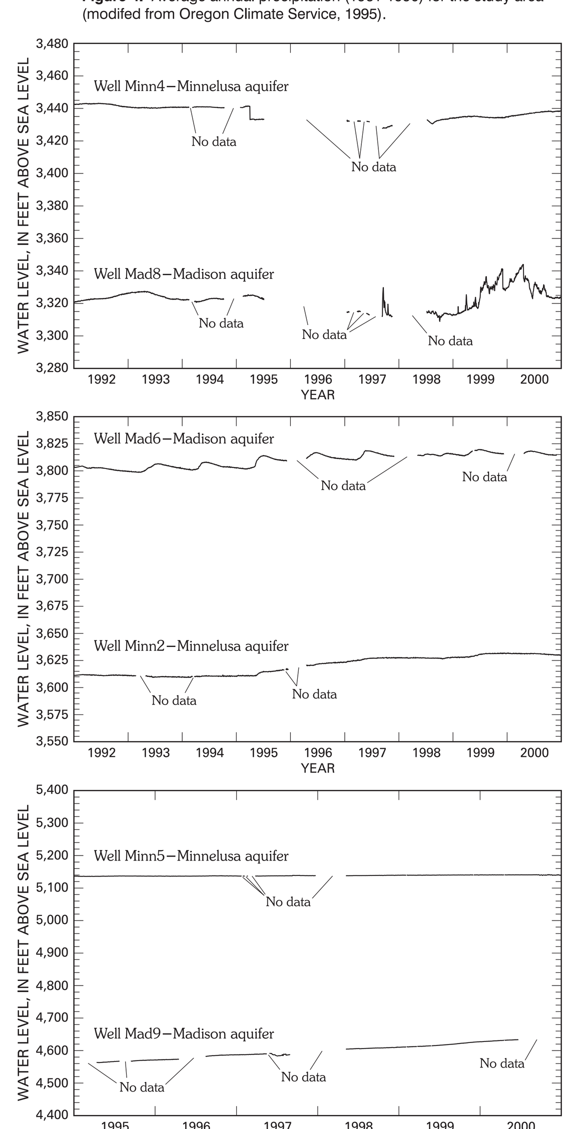


Figure 5. Water-level hydrographs for paired Minnelusa and Madison wells. Water levels from Wyoming State Engineer's Office (Larry Porter, written commun., 2002). Well locations shown in figure 1 (sheet 1).

The Madison aquifer (Lower Mississippian) in the Black Hills uplift is primarily composed of massive, gray to buff limestone that is locally dolomitic (DeWitt and others, 1986; Strobel and others, 1999). The thickness of the Madison Limestone varies throughout the Black Hills area, probably because of karst topography that developed prior to deposition of overlying formations (DeWitt and others, 1986). In the western Black Hills, DeWitt and others (1986, fig. 4, p. 11) report a thickness of 300-630 ft for the Madison Limestone. Primary permeability probably is low in the Madison aquifer because it is mainly composed of carbonate rocks; however, development of extensive secondary porosity and permeability from numerous fractures and solution openings accounts for the high yields of wells completed in the Madison aquifer in selected areas (Miller, 1976; Kelly and others, 1981; Kyllonen and Peter, 1987; Strobel and others, 1999). Dissolution of rocks in parts of the Madison aquifer has resulted in extensive past and ongoing development of karst solubility features and related secondary porosity and permeability (Sando, 1974). Numerous caves, fractures, and other karst features have been identified in the Madison aquifer in South Dakota and Wyoming, particularly the upper part (Sando, 1974; Peter, 1985; Kyllonen and Peter, 1987; Greene and Rahn, 1995). Greene and Rahn (1995) also noted that principal cavern development (and consequently, principal direction of transmissivity) in the Madison aquifer in the Black Hills area in South Dakota is oriented along the direction of ground-water flow. Porosity and permeability in the Madison aquifer in the Northern Great Plains appear to be higher in the crystalline dolomites than limestones comprising the aquifer (Thayer, 1983; Peterson, 1984). Large water yields have been reported for wells completed in more permeable zones of the Madison aquifer (probably where development of karst features has occurred) (Miller, 1976; Feathers and others, 1981; Kelly and others, 1981; Kyllonen and Peter, 1987); potential areas with high yields (more than 500 gallons per minute) from the Madison aquifer throughout the Northern Great Plains were discussed in MacCary and others (1983). Recharge to the Madison aquifer in the Black Hills area in Wyoming and South Dakota is primarily from infiltration of precipitation on outcrops and from streamflow losses (Swenson, 1968a, 1968b; Wyoming State Engineer's Office, 1974; Hortness and Driscoll, 1998; Carter and others, 2001a).

Springs discharging from the Madison aquifer provide flow for many streams in the study area (Wyoming State Engineer's Office, 1974, 1976; Boner and others, 1976; Glass and Sultz, 1992). In some areas, springs discharge near the contact of the Minnelusa and Madison aquifer.

Structural contours showing the configuration and altitude of the top of the Madison aquifer (this sheet) constructed for this and earlier investigations (Head and others, 1979; Kyllonen and Peter, 1987) show that the Madison aquifer, like the Minnelusa aquifer, dips away from uplift areas (Black Hills and Bear Lodge Mountains). Structural contours constructed during this investigation for the northern part of the study area range from about 6,000 ft above sea level to about 2,000 ft above sea level in most of the northern part of the study area; in the Bear Lodge Mountains area, the top of the aquifer is about 4,000 to 5,000 ft above sea level. In the southern part of the study area (sheet 4), structural contours range from about 6,000 feet above sea level in the northeast to about 2,000 feet below sea level in the southwest.

Water from the Madison aquifer in the Black Hills area of Wyoming is used primarily for municipal (public) water supplies. Three communities within the study area, Newcastle, Osage, and Sundance (fig. 1, sheet 1), obtain all or part of their public water supply from the Madison aquifer (Sundance has a well completed in both the Minnelusa and Madison aquifers).

Municipal water withdrawals from the Madison aquifer in the Powder River Basin in Wyoming increased between 1973 and 1993, while industrial use decreased (Wyoming State Engineer's Office, 1993). The communities of Gillette, Upton, Newcastle, Pine Haven, Hulett, Sundance, Glenrock, Douglas, Osage, Kaycee, and Midwest use the Madison aquifer for some or all of their potable water supply. By 1993, these communities were withdrawing about twice the amount of water withdrawn in 1973. In contrast, water withdrawn from the Madison aquifer for industrial purposes, primarily secondary oil recovery, decreased from about 20,000 acre-feet in 1973 to about 5,000 acre-feet in 1993. Water from the Madison aquifer along the western edge of the Black Hills also is used for agricultural irrigation, feed lot operation, and domestic use.

Potentiometric Surface

The potentiometric surface constructed for this study shows that in most of the study area, the direction of ground-water flow in the Madison aquifer is similar to the direction of flow in the Minnelusa aquifer. In the study area in Wyoming, ground water in the Madison aquifer generally flows radially outward (primarily to the west) and generally downdip from the outcrop area of the aquifer and the outcrop area in South Dakota (most of the Madison aquifer outcrop area is in South Dakota (DeWitt and others, 1989; Strobel and others, 1999)). In the northern part of the study area, east of the Bear Lodge Mountains and northeast of Sundance, contours constructed during this study indicate ground water in the Madison aquifer primarily flows to the northeast. Earlier potentiometric surfaces constructed for the Madison aquifer in Wyoming (Swenson, 1974; Wyoming State Engineer's Office, 1974; Swenson and others, 1976; Kyllonen and Peter, 1987), South Dakota (Kyllonen and Peter, 1987; Strobel and others, 2000a), or for the Madison aquifer and equivalent rocks in Wyoming, South Dakota, and Montana (Miller and Strausz, 1980, Downey and Dinwiddie, 1988) suggest similar movement in the study area and also show that ground water in the Madison aquifer in Wyoming, South Dakota, and Montana in the immediate vicinity of the Black Hills generally flows radially outward from the aquifer outcrop areas that encircle the center part of the uplift (igneous and metamorphic core).

In the northern part of the study area (sheet 1), the altitude of the potentiometric surface ranged from about 5,800 ft above sea level in the southeast near the Wyoming-South Dakota State line to about 3,700 ft above sea level in the northeast near the Wyoming-South Dakota State line. In the southern part of the study area (sheet 2), contours were constructed only for the northeast, and the altitude of the potentiometric surface ranged from about 5,700 ft to about 3,800 ft above sea level.

Water Levels

Water levels in the Madison aquifer generally increased during 1995-99, a period of above-average precipitation. An example hydrograph for well Mad6 illustrates this point (fig. 3, sheet 2). Water-level changes observed in well Mad6 appear to correspond to changes in monthly precipitation at Sundance, Wyoming (fig. 3, sheet 2).

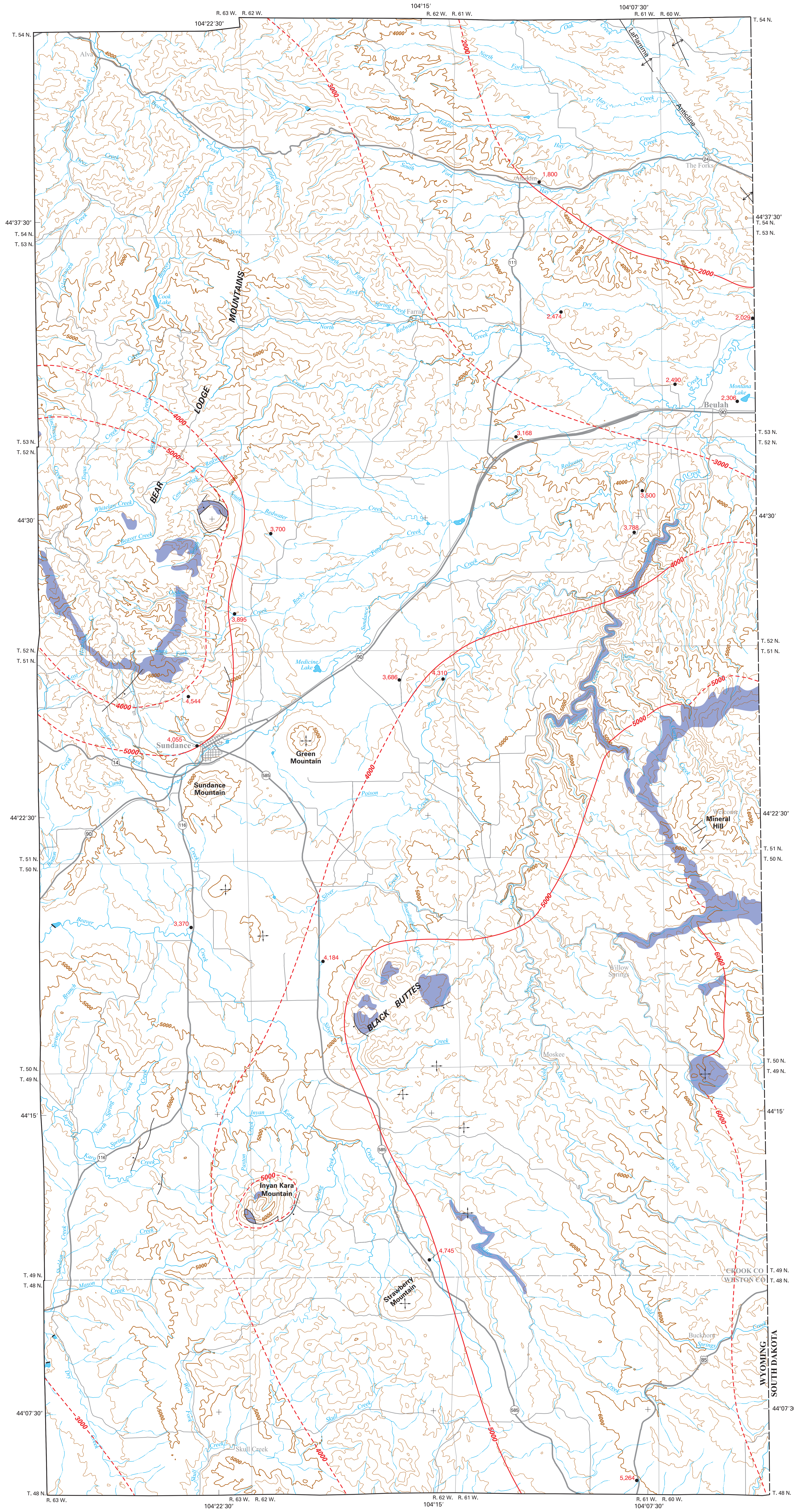
Tritium

Tritium concentrations in ground-water samples collected from one spring and seven wells in the Madison aquifer during this and an earlier study are listed in table 1 (sheet 2). Samples collected from two of the seven wells and the spring had tritium concentrations suggestive of at least some recharge since 1953 (greater than about 0.8 TU). The sample collected from spring Mad5 had a relatively high tritium concentration (13.7 TU), suggesting that most, if not all, of the water sampled from this spring was recharged since 1953. Although the spring probably discharges directly from the Madison aquifer, the close proximity of the spring to the outcrop of the Minnelusa aquifer suggests that some water may be from the Minnelusa aquifer as a result of hydraulic connection between the two aquifers. If the aquifers are hydraulically connected, the water sample collected from spring Mad5 could be a mixture of younger water from the Minnelusa aquifer with older water from the Madison aquifer. The highest tritium concentration (24.1 TU) was detected in a sample collected from well Mad4; the concentration is high enough to suggest that most, if not all, of the water sampled from this well was recharged since 1953.

POTENTIAL FOR VERTICAL FLOW BETWEEN AQUIFERS

The potential for vertical water movement between aquifers can be determined by examining hydraulic heads in wells completed at different depths in the aquifers. Ground water moves from areas of high hydraulic head to low hydraulic head. The potential for vertical movement is proportional to the differences in hydraulic head between the aquifers.

Water levels were examined at three locations with paired monitoring wells comprising one well completed in the Minnelusa aquifer and one well completed in the underlying Madison aquifer (fig. 5, this sheet). Hydraulic head differences were large at all three locations during the periods of continuous water-level monitoring examined. The differences in hydraulic head at paired wells Minn4 and Mad8 and at paired wells Minn5 and Mad9 indicated the potential for downward movement of ground water from the Minnelusa aquifer into the underlying Madison aquifer. The potential direction of ground-water movement is reversed in paired wells Mad6 and Minn2, indicating the potential for upward movement of water from the Madison aquifer into the underlying Minnelusa aquifer.



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Potentiometric Surfaces, Altitudes of the Tops, and Hydrogeology of the Minnelusa and Madison Aquifers, Black Hills Area, Wyoming

by
Timothy T. Bartos, Laura L. Hallberg, and Kathy Muller Ogle
2002